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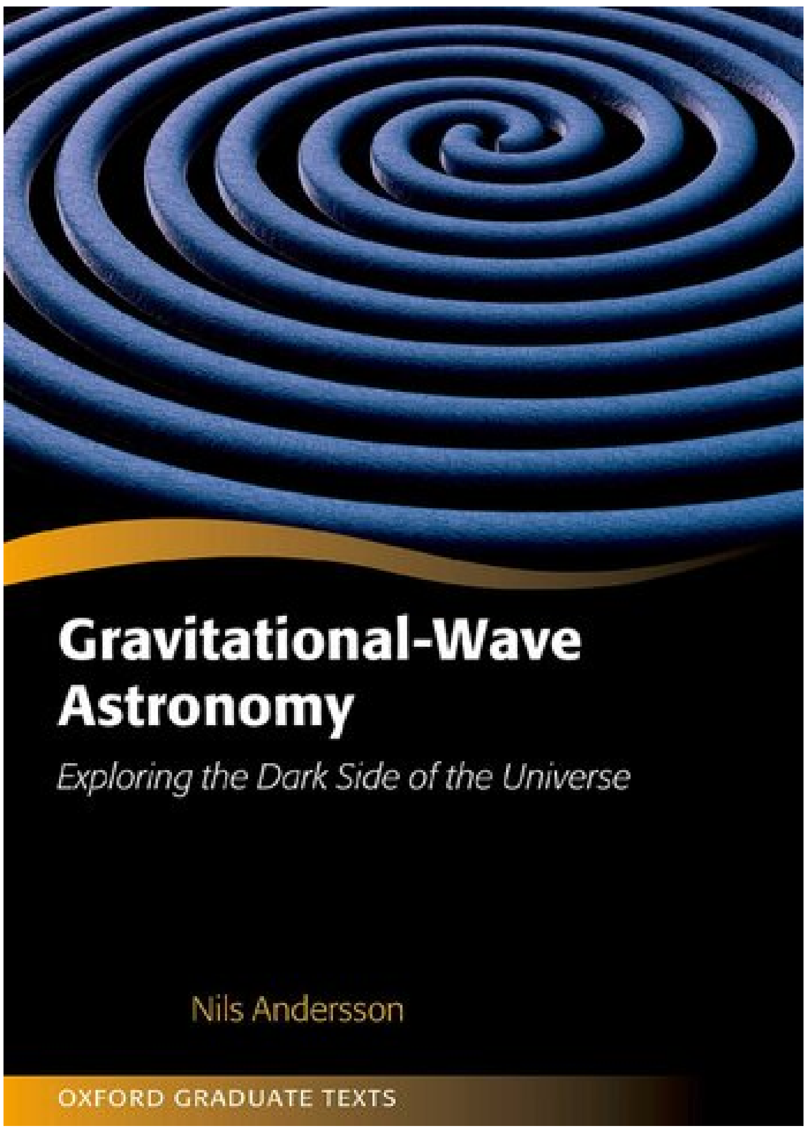

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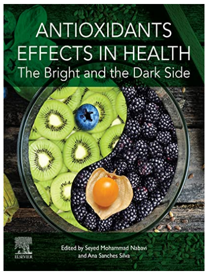

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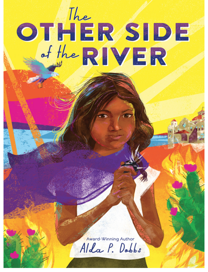

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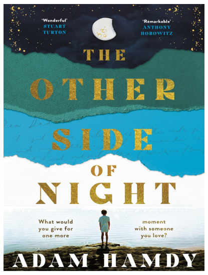

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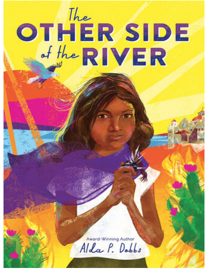

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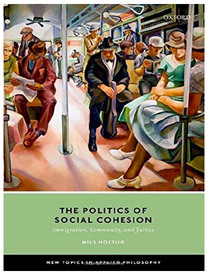

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Gravitational-Wave Astronomy

Exploring the Dark Side of the Universe

Nils Andersson

OXFORD GRADUATE TEXTS

GRAVITATIONAL-WAVE ASTRONOMY

Gravitational-Wave Astronomy

Exploring the Dark Side of the Universe

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Preface

Whenever you are writing a book, people are bound to ask: 'What kind of book is it? Who is it for?' These questions are reasonable, but the answers may not be that obvious. You may, for example, have embarked on the project simply because it seemed like a good idea at the time. So, with this in mind, what kind of a book is this? Having lived with it for longer than I care to figure out, I still find it difficult to give a clear answer. It is much easier to explain what it is not. This book is not an exhaustive review of gravitational-wave astronomy. At least not in the sense that it provides a 'complete' reference list and a detailed account of the historical developments of the ideas and the scope of the field. It is much more 'subjective' than that. This may be frustrating to colleagues that have contributed to the developments over the last several decades, but the reality is that I had to make choices. It was simply not manageable to peek into (and report back on) every nook and cranny, no matter how fascinating this might have been. Instead, I have tried to provide an entry point to the vast (and rapidly growing!) literature on the different aspects of gravitational waves and related astrophysics.

In essence, I have tried to build a bridge across different areas of physics that have fascinated me for a long time. On the one hand, we have gravity—with Einstein's warped spacetime providing an astonishing example of what the human mind is capable of. On the other hand, there is the extraordinary range of astrophysics and cosmology that comes into play when we try to understand the gravitational-wave sky. And finally, we need to consider the sublime technology that was developed to catch these faint whispers from the distant Universe. This book maps out a journey through this complex landscape—introducing a combination of overlapping areas of research, many of which require their separate books for a fair treatment. The different chapters (especially in the second part) are intended to narrow the gap between a basic understanding and current research. An important part of this involves introducing the relevant language—making the involved concepts less 'mysterious'.

The book is intended to work as a platform, sufficiently low that anyone with an interest in gravitational waves can scramble onto it, but at the same time high enough that it connects with current research—and exciting discoveries that are happening right now. It may only be an introduction, but I think it has potential... If you are an astronomer and you want a basic understanding of this new window to the Universe, including a brief (relatively self-contained) glimpse at Einstein's theory, then this book may work for you. Similarly, if you spend most of your time analysing data from gravitational-wave detectors and you would like a better picture of what you are looking for (and perhaps why theorists find it so difficult to make firm predictions) then other parts of the book could work for you. Finally, there is a connection to nuclear physics—which is natural, since gravitational-wave signals from neutron stars may help constrain our ideas

for matter at extreme densities. Relevant aspects are addressed at various places in the book, which may help nuclear and particle physicists appreciate how their work fits into the bigger picture. Whichever direction you are coming from, and regardless of where you are going, this book may be of interest to you.

In terms of teaching, the scope of the book is likely too vast for a single undergraduate or masters-level course. But the material is flexible. The first part introduces the key ideas, following a general overview chapter and including a brief reminder of Einstein's theory. This part can be taught as a (fairly) self-contained undergraduate one semester course. In fact, the material is based on a course we have had on the books for over a decade. So I know it works. Depending on the background and interest of the students, I would select topics from the second (much longer) part of the book to connect with the actual state of the art. The chapters are written to work as 'set pieces' with core material that can be adapted to specific lectures and additional material that provide context and depth. At least that's the way I like to think about it. Some of the chapters have been road-tested at summer schools and other events so I am confident they work. The one thing that is missing in terms of teaching material is exercises. However, it is quite easy to identify steps that need filling in and to come up with questions that go beyond the material, so this should not be a major issue.

Before we embark on the journey, it is useful to make a few comments on notation and conventions. Throughout the book I have chosen to work with a spacetime metric with signature $+2$. There is one exception: The discussion of the Newman–Penrose formalism used to discuss the dynamics of spinning black holes. I have adopted the convention that spacetime indices are given by letters from the beginning of the alphabet, $a, b, c, \ldots$, while spatial indices start with $i, j, k, \ldots$. Many text books use Greek letters for the former. Repeated indices (spacetime or spatial) indicate summation.

With these formalities out of the way, let's get started.

Contents

A long time ago, in a galaxy far away, the two black holes edged closer. Dancing around each other in a nearly perfect circle. Drawn together by gravity, through the emission of gravitational waves. Faint ripples encoded the change in gravity over eons. In the last few moments the motion grew frantic. A storm of warped space and time raged as the two objects came together. An energy equal to the obliteration of several suns was released in a fraction of a second. Then it was over. All that remained was a single black hole. And empty space.

The signal moved unchanged over the vast distances of space until, after more than a billion years, it reached the Earth. When the signal was created, this insignificant blue planet hosted single cell organisms. When the signal arrived, there was an advanced civilization. A civilization curious about the Universe. A civilization with technology to catch the elusive spacetime whisper. Their advanced detectors registered a disturbance.

This was the beginning.

1

Opening the window

1.1 The beginning

The first direct detection of gravitational waves was announced to the world on the 11th of February 2016 with a triumphant 'We did it!'. The signal, which had been picked up by the two LIGO detectors on the 14th of September 2015, matched the predictions from numerical simulations of the merger of a pair of black holes with masses $36M_\odot$ and $29M_\odot$, forming a larger black hole with mass $62M_\odot$ (Abbott *et al.*, 2016*b*). The missing mass—the equivalent of about 3 solar masses—had been radiated as gravitational waves. This extraordinary event, which only lasted a fraction of a second, was the most powerful astronomical event ever observed. It was the beginning of a new kind of astronomy.

The breakthrough detection came nearly a century after Einstein's prediction that changes in gravity should propagate as waves (Einstein, 1916). It was an extraordinary moment of success, following decades of technology development, political wrangling to secure funding, and several false starts. It was a moment of glory, rewarding an enormous amount of patient and hard work from a lot of people.

The LIGO project was initiated in the early 1990s Abramovici *et al.* (1992) and the first generation of kilometre-scale gravitational-wave interferometers reached their initial design sensitivity in a broad frequency window in November 2005 (during the fifth science run, S5). More than one year's worth of quality data was taken during the following science run (S6) in 2009–10. Many research papers were written, but no signals were found. After a couple of years' downtime to improve the technology, the first 'observing run' (O1) of the advanced interferometers started in September 2015. The immediate detection of the black-hole signal led to a collective sigh of relief. It had been a long journey.

The first detection brought the promise of gravitational-wave astronomy into sharp focus. It was much more than a confirmation that gravitational waves exist and that we can catch them. We learned that there are double black-hole systems in the Universe and that they merge due to the emission of gravitational radiation. The observed signal agreed with the predictions from general relativity, showing the expected inspiral, merger, and ringdown phases seen in numerical supercomputer simulations (Chapter 19). It was the first test of Einstein's theory in a dynamical, strong-field setting. The signal allowed us to identify more massive black holes than so far found in X-ray binaries, and it also provided interesting constraints on the spin of the individual black holes.

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The underlying theory may be complex, but the observed signal was simple. It swept upwards in amplitude and frequency from 30 to 250 Hz in a perfect example of the anticipated chirp (see the time-frequency plots in the lower panels of Figure 1.1). At its peak, the gravitational-wave strain, $h \approx 10^{-21}$, corresponded to a luminosity equivalent to emitting the mass-energy of about 200 suns in a second. The event took place 1.3 billion light years from the Earth (Abbott *et al.*, 2016*b*). In terms of the Universe, it was ancient history.

Binary signals, like GW150914, carry unique information on the masses and spins of the sources. In the case of neutron stars, the gravitational waves also encode the internal structure, which depends on the state of matter at extreme densities. In essence, gravitational-wave observations have the potential to probe many fundamental physics issues. Given the weakly interacting nature of gravitational waves, the information they carry provides an important complement to electromagnetic observations. In fact, they

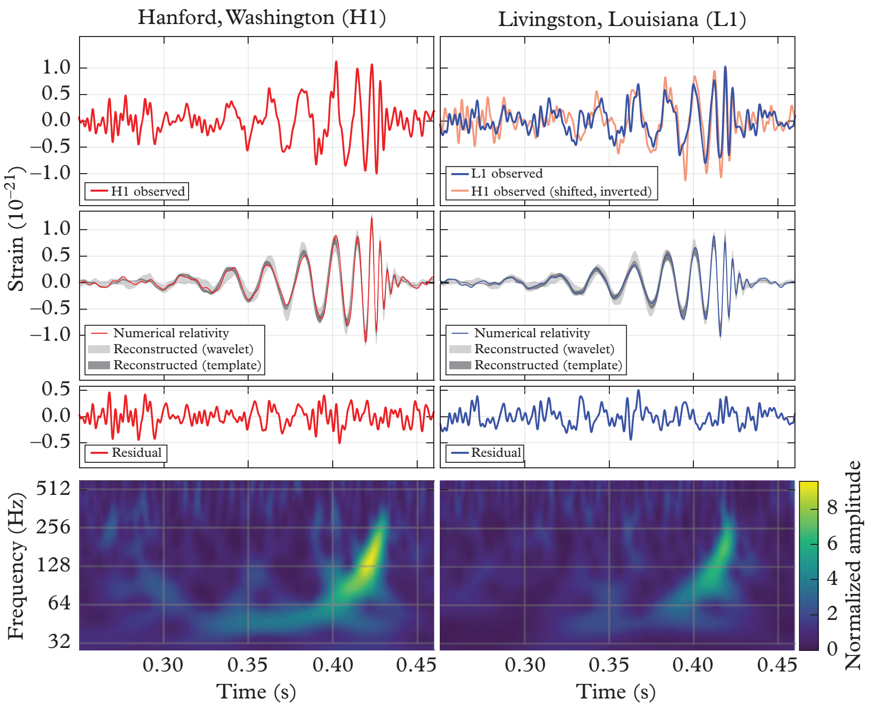

Figure 1.1 *The first gravitational-wave signal (GW150914) observed by the LIGO Hanford (H1, left) and Livingston (L1, right) interferometers. The top row shows how the gravitational-wave strain varied with time in the two detectors (with a direct comparison after a time shift of 10 ms corresponding to the travel time—at the speed of light—between the two instruments). The middle row compares the signal to results from numerical relativity simulations, showing inspiral, merger, and ringdown of two coalescing black holes. The bottom row gives a time-frequency representation of the gravitational-wave strain, again showing the signal frequency and strength increasing with time. (Reproduced from Abbott et al. (2016b), Creative Commons Attribution 3.0 License.)*

shed light on aspects that cannot be probed by traditional means, like the internal dynamics of a supernova explosion or quantum fluctuations in the very early Universe just after the Big Bang. In order to understand the wide range of possibilities, we need to explore the mechanisms that generate gravitational waves in the first place. We need to be able to predict the character of the signals and consider the challenges associated with detecting them. As this involves many complex questions, and it is important to appreciate the context, we need to start from the beginning.

1.2 A new kind of astronomy

With his theory of general relativity, Einstein revolutionized our view of space and time (Einstein, 1915). By explaining gravity in terms of the geometry of a combined spacetime he provided a fresh perspective on the Universe. This led to the introduction of exciting concepts that have become part of mainstream culture. Most notably, *black holes*, formed when massive stars die, and the *Big Bang*, the explosion which gave birth to the Universe some 14 billion years ago. Moreover, Einstein's general relativity is a *dynamic* theory of gravity, where space and time are flexible concepts. The theory predicts that changes in gravity propagate as waves, ripples in spacetime moving at the speed of light. These *gravitational waves* are elusive. For decades they caused debate and controversy[1] and, until recently, attempts to detect them proved futile.

It is not really surprising that the detection of gravitational waves proved such a challenge. Early generations of instruments may have been remarkably sensitive—from an everyday life point of view—but they would still only have been able to catch unique events in our own Galaxy and its immediate neighbourhood and such events are rare. Take supernova explosions, which occur only a few times per century in a typical galaxy, as an example. Population modelling and our understanding of stellar evolution tell us that we need to reach further out into the Universe if we want to detect such events. Exactly how far, we do not know at this point. It is relatively easy to work out the energy that must be released in order for a given source to be detectable, but very difficult to provide a reliable model of the complex physics associated with most gravitational-wave scenarios. Yet, it is clear that we will always be dealing with faint signals. This is in sharp contrast with mainstream astronomy, where observations are traditionally made at large signal-to-noise ratios.

As the sensitivity of the available detectors improved—gradually—we learned valuable lessons. It is fairly easy to identify 'milestone' results leading up to the breakthrough in 2015. For example, the initial LIGO–Virgo detectors were sensitive enough that they would have been able to catch a gravitational-wave burst from a Milky Way supernova, should one have occurred during the series of science runs (Abadie *et al.*, 2012). The absence of detections hardly challenged our view of the Universe, but it was nevertheless an important step. The fact that the gravitational-wave contribution to the spin-down of

[1] A meeting at Chapel Hill in January 1957 is often seen as the turning point. In particular, Richard Feynman famously provided a 'sticky bead' argument to demonstrate that gravitational waves must carry energy.

the Crab Pulsar—a neutron star born in a supernova recorded by Chinese astronomers in 1054—can be constrained to be less than a fraction of a percent of the observed rate (Abbott *et al.*, 2008*a*) may only be mildly interesting from the astrophysics point of view, but it was nevertheless a milestone achievement as it constrained the asymmetry of a distant astronomical object in a way that could not be done by other means.

Gravitational-wave astronomy is a fascinating area that involves a range of complex issues, from the development of detector technology to data-handling techniques and theory modelling. In order to progress, we need to improve on all these aspects. As we celebrate the first successful detections, it is useful to keep in mind the effort behind the success. Over decades, generations of scientists turned an impressive engineering project into an astronomical observatory. This was a spectacular achievement, but we are far from done. Future observing runs will probe a much larger volume of space. We will have more, better quality, data. Conservative population synthesis models suggest that we will detect many inspiralling compact binaries (consisting of black holes and/or neutron stars) every year. Given that such 'bread and butter' binary signals are well understood (and depend very little on the composition of the binary companions) and the data analysis algorithms are (more or less) developed, this should allow us to probe the parameters of such systems, shedding light on the cosmic compact binary population and the relevant formation channels.

The wider range of gravitational-wave sources put more emphasis on the involved physics and high-quality modelling of relevant astrophysical scenarios. Inevitably, this requires an exchange of expertise with mainstream astronomers. For a long time the emphasis was on detector development and data analysis strategies. As we establish this new area of astronomy, we need rapid change. We need to address challenging modelling problems. Many relevant gravitational-wave scenarios involve extreme physics that cannot be tested in the laboratory and precision searches require an understanding beyond 'order of magnitude' precision.

The future is, of course, bright. Once third-generation detectors, like the Einstein Telescope (Punturo *et al.*, 2010; Sathyaprakash *et al.*, 2012) or the Cosmic Explorer (Abbott *et al.*, 2017*c*), come on-line we will firmly be in the era of gravitational-wave astronomy. These instruments will improve the broadband sensitivity by another order of magnitude, reaching another factor of 1,000 in volume of space. This may seem remote, given that such detectors are still at the design stage, but we need to consider their promise now. We are talking about 'big science' and we need to understand its potential in order to argue the case for building such hugely expensive instruments. It is relevant to ask what we can hope to achieve with an Einstein Telescope, but not (necessarily) with Advanced LIGO. How much better can we do with (roughly) an order of magnitude improvement in sensitivity? Are there situations where this improvement is needed to see the signals in the first place, or is it a matter of doing better astrophysics by getting improved statistics and more precise parameter extraction? There are many interesting and complicated issues to consider.

Perhaps in contrast, it is straightforward to argue the case for a space-based detector, like the LISA project which is expected to launch in 2034 to address the European

Space Agency's science theme of the Gravitational Universe (Amaro-Seoane *et al.*, 2017). Sensitive to low-frequency gravitational waves, LISA is perfectly tuned to typical astronomical timescales (hours to minutes). If the instrument works as planned—and there is no reason to think that it should not, given the impressive results from the LISA Pathfinder (Armano *et al.*, 2018)—detection is guaranteed. In fact, many known binary systems can be used to verify that the detector is working as intended. The challenges that the LISA project faces are different. Given the number of, in principle, detectable binaries in the Galaxy, the data analyst may suffer an embarrassment of riches. The science may (to some extent) be confusion limited. However, the fact that LISA is sensitive to signals from supermassive black holes (either merging or capturing smaller objects) throughout the Universe makes it an extremely exciting mission.

On a timescale of 20 years or so we should have a network of high-precision instruments searching the skies for gravitational-wave signals over a range of up to eight decades in frequency; see Figure 1.2. These detectors will provide us with unprecedented insights into the dark side of the Universe, and allow us to probe much exciting physics. Further improvements in data quality may allow us to extract the gravitational-wave component in the cosmic microwave background. In addition, ultra-low-frequency gravitational waves are likely to have been detected by pulsar timing arrays. In parallel, we can expect to see breakthroughs in related areas of physics. Following the detection of the Higgs boson by the Large Hadron Collider, the colliders probe higher energies and may eventually find evidence for supersymmetry. Experiments aimed at detecting dark

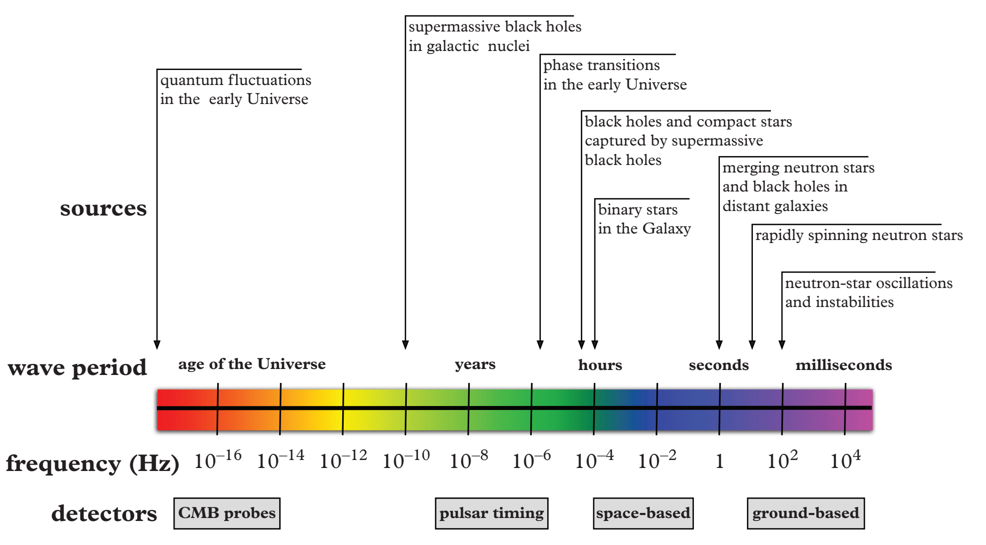

Figure 1.2 *The spectrum of anticipated gravitational-wave sources and the different methods that may be used to detect them, across more than 20 decades in frequency. The physical timescales range from the age of the Universe to a fraction of a millisecond.*

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North Wind's Malice. 1920.

*One Heavenly Night. 1930.
One of the Finest. 1919.
One Week of Life. 1919.
*Palmy Days. 1931.
*Partners Again. 1926.
Partners of the Night. 1920.
Pest. 1919.
*Potash and Perlmutter. 1923.
*Raffles. 1930.
*Real Glory. 1939.
*Rescue. 1929.
Return of Tarzan. 1920.
*Roman Scandals. 1933.
*Splendor. 1935.
Spotlight Sadie. 1919.
*Stella Dallas. 1926, 1937.
Strange Boarder. 1920.
*Strike Me Pink. 1936.
Stronger Vow. 1919.
*Tarnish. 1924.
*These Three. 1936.
*They Shall Have Music. 1939.
*Thief in Paradise. 1924.
*This Is Heaven. 1929.
Through the Wrong Door. 1919.
Tonight or Never. 1931.
Truth. 1920.
*Two Lovers. 1928.
*Unholy Garden. 1931.
*We Live Again. 1934.
*Wedding Night. 1935.
When Doctors Disagree. 1919.
*Whoopee. 1930.
*Winning of Barbara Worth. 1926.
*Woman Chases Man. 1937.
*Wuthering Heights. 1939.

GOLDWYN (SAMUEL) INC., LTD.
*Hurricane. 1938.

GOLDWYN CORPORATION.
Strictly Confidential. 1919.

GOLDWYN-COSMOPOLITAN.
Through the Dark. 1924.

GOLDWYN DISTRIBUTING CORPORATION.
Artistic Enemies. 1920.
At It Again. 1920.
Border Legion. 1919.
Counter Plot. 1920.
Fingers and Pockets. 1920.
Fly in the Ointment. 1920.
Hearts and Hammers. 1920.
High Pockets. 1919.
Love on Rollers. 1920.
Matrimoniacs. 1920.
Money Mix-up. 1920.
Mum's the Word. 1920.
Oh, Girls! 1920.
Professional Ethics. 1921.
Rarebits. 1920.
*Sherlock Holmes. 1922.
Treat 'Em Kind. 1920.
What Could Be Sweeter. 1920.

GOLDWYN PICTURES CORPORATION.
*Ace of Hearts. 1921.
*Adventures and Emotions of Edgar Pomeroy. (Serial)
*All Woman. 1918.
*All's Fair in Love. 1921.
*Almost a Husband. 1919.
*Always the Woman. 1922.
*Artistic Enemies. 1920.
*At It Again. 1920.

*Auction Block. 1917.
*Baby Mine. 1917.
*Back to the Woods. 1918.
Be My Wife. 1921.
*Beating the Game. 1921.
*Beloved Traitor. 1918.
*Blind Bargain. 1922.
*Blooming Angel. 1919.
*Bondage of Barbara. 1919.
*Bonds of Love. 1919.
*Boys Will Be Boys. 1921.
Brand. 1919.
*Branding Iron. 1920.
*Broken Chains. 1922.
*Brothers Under the Skin. 1922.
*Bunty Pulls the Strings. 1920.
*Cabinet of Dr. Caligari. 1921.
*Christian. 1923.
*Cinderella Man. 1917.
*City of Comrades. 1919.
*Come On Over. 1922.
*Concert. 1921.
*Counter Plot. 1920.
Crimson Gardenia. 1919.
Cup of Fury. 1919.
*Cupid, the Cowpuncher. 1920.
*Danger Game. 1918.
*Dangerous Curve Ahead. 1921.
Dangerous Days. 1920.
*Darn That Stocking! 1920.
*Daughter of Mine. 1919.
*Daydreams. 1918.
*Day of Faith. 1923.
*Dodging a Million. 1918.
*Dollars and Sense. 1920.
Don't Neglect Your Wife. 1921.

*Double Dyed Deceiver. 1920.
*Doubling for Romeo. 1921.
*Duds. 1920.
Earthbound. 1920.
*Eternal Magdalene. 1919.
*Eternal Three. 1923.
*Excess Baggage. 1920.
*Face in the Dark. 1918.
*Fair Pretender. 1918.
*Fear Woman. 1919.
*Fields of Honor. 1918.
*Fighting Odds. 1917.
*Fingers and Pockets. 1920.
*Flag of Mothers. 1918.
*Floor Below. 1918.
*Fly in the Ointment. 1920.
*For the Freedom of the East. 1918.
*For Those We Love. 1921.
*Forget-Me-Not. 1920.
*Friend Husband. 1918.
*From the Ground Up. 1921.
*Gay Lord Quex. 1919.
*Gid-ap Napoleon. 1921.
*Gimme. 1923.
Girl from Outside. 1919.
*Girl with the Jazz Heart. 1920.
*Glorious Adventure. 1918.
Glorious Fool. 1921.
*Go West Young Man. 1918.
*Godless Men. 1920.
Going Some. 1920.
*Goldwyn-Bray Pictographs. (Serial)
*Grand Larceny. 1922.
*Great Accident. 1920.
*Great Lover. 1920.
*Grim Comedian. 1921.

*Guile of Women. 1920.
*Happy Hooligan in a Close Shave. 1921.
*Head over Heels. 1922.
*Hearts and Hammers. 1920.
*Heartsease. 1919.
*Help Yourself. 1920.
*Hidden Fires. 1918.
*Highest Bidder. 1920.
*His Back Against the Wall. 1922.
*His Own Law. 1920.
*His Wife's Husband. 1920.
*Hold Your Horses. 1920.
*Home Brewed Youth. 1921.
*Honest Hutch. 1920.
*Hungry Hearts. 1922.
*In the Palace of the King. 1923.
*Indigo Sunday. 1921.
*Invisible Power. 1921.
It's a Great Life. 1920.
*Jes' Call Me Jim. 1920.
*Jinx. 1919.
*Joan of Plattsburg. 1918.
*Jubilo. 1919.
*Just for Tonight. 1918.
*Just Out of College. 1920.
*Kingdom of Youth. 1918.
*Knock 'Em Cold. 1920.
*Last Moment. 1923.
*Laughing Bill Hyde. 1918.
*Leave It to Susan. 1919.
*Little Dears. 1920.
*Little Shepherd of Kingdom Come. 1920.
*Look Your Best. 1923.
*Lord and Lady Algy. 1919.
*Lost and Found. 1923.
*Love on Rollers. 1920.

*Loves of Letty. 1919.
*Mad Love. 1923.
*Madame X. 1920.
*Made in Heaven. 1921.
*Man and His Money. 1919.
*Man from Lost River. 1921.
*Man Who Had Everything. 1920.
*Man with Two Mothers. 1922.
*Matrimoniacs. 1920.
*Milestones. 1920.
*Mr. Barnes of New York. 1922.
*Money Mad. 1918.
*Money Mix-up. 1920.
*Much Needed Rest. 1920.
*Mum's the Word. 1920.
*Name the Man. 1924.
*Nearly Married. 1917.
*Nellie, the Beautiful Cloak Model. 1924.
Night Rose. 1921.
North Wind's Malice. 1920.
*Officer 666. 1920.
*Oh, Girls! 1920.
*Oh, Johnny! 1918.
*Old Nest. 1921.
*One Dollar Down. 1920.
*One of the Finest. 1919.
*One Week of Life. 1919.
*Our Little Wife. 1918.
*Out and In. 1920.
Out of the Storm. 1920.
*Paliser Case. 1919.
*Pardon My French. 1921.
Partners of the Night. 1920.
*Peace of Roaring River. 1919.
*Peck's Bad Girl. 1918.
Penalty. 1920.

*Perfect Lady. 1918. LP13091, LP15755.
*Perfect 36. 1918.
*Pest. 1919.
*Pinto. 1919.
*Polly of the Circus. 1917.
*Poor Relation. 1921.
*Poverty of Riches. 1921.
Prisoners of Love. 1921.
*Professional Ethics. 1921.
*Racing Strain. 1918.
*Rarebits. 1920.
*Recoil. 1924.
*Red Lights. 1923.
Remembrance. 1922.
*Rendezvous. 1923.
*Return of Tarzan. 1920.
*Road to Ruin. 1920.
*Roads of Destiny. 1921.
Scratch My Back. 1920.
Silver Horde. 1920.
*Sin Flood. 1921.
*Sis Hopkins. 1919.
*Six Days. 1923.
*Slave of Desire. 1923.
*Slim Princess. 1920.
*Snowblind. 1921.
*Splendid Sinner. 1918.
*Spotlight Sadie. 1919.
*Spreading Dawn. 1917.
*Stop Thief. 1920.
*Strange Boarder. 1920.
*Stranger's Banquet. 1922.
*Street Called Straight. 1919.
*Strictly Confidential. 1919.
*Sunshine Alley. 1917.
*Sure Cure. 1920.

*Tale of Two Worlds. 1921.
*Thaïs. 1917.
*Thirty a Week. 1918.
*Three Weeks. 1924.
*Three Wise Fools. 1923.
*Through the Wrong Door. 1919.
*Toby's Bow. 1919.
Too Fat To Fight. 1918.
*Treat 'Em Kind. 1920.
True As Steel. 1924.
*Truth. 1920.
*Turn of the Wheel. 1918.
*Two Dollars, Please! 1920.
*Unwilling Hero. 1921.
*Upstairs. 1919.
*Venus Model. 1918.
*Voice in the Dark. 1920.
*Wallflower. 1922.
*Watch Your Step. 1922.
*Water, Water Everywhere. 1919.
*What Could Be Sweeter. 1920.
*What Happened to Rosa. 1920.
*When Doctors Disagree. 1919.
*When Martin Gets Here. 1921.
*When Romance Rides. 1922.
*Why Worry. 1921.
*Wild Oranges. 1922.
*Woman in Room 13. 1920.
*Woman on the Index. 1919.
Yellow Men and Gold. 1922.
*You'd Better Get It. 1921.

GOLDWYN STUDIOS.
All's Fair in Love. 1921.
Beating the Game. 1921.
Boys Will Be Boys. 1921.

Concert. 1921.
Dangerous Curve Ahead. 1921.
Don't Neglect Your Wife. 1921.
Guile of Women. 1920.
Highest Bidder. 1920.
Invisible Power. 1921.
Made in Heaven. 1921.
Old Nest. 1921.
Snowblind. 1921.
Tale of Two Worlds. 1921.
What Happened to Rosa. 1920.

GOLLAN, CAMPBELL.
Wild Oats. © 1915, 1916.

GOLLOMB, JOSEPH.
Man Hunt. 1916.

GONZALES, ENRIQUE.
*Tropical Love. © 1921.

GOOD HUMOR ICE CREAM COMPANY.
Making Good with Good Humor. 1937.

GOOD-WILL PICTURES, INC.
*Why. © 1935.

GOODALL, RICHARD.
Clown Hero. © 1913.
In the Shadows of the Rockies. © 1918.
Trail of the Cigarette. © 1920.

GOODALL MILLS.
Amazing Story of Mohair. 1929.

GOODCHILD, GEORGE.
Colorado Pluck. 1921.
Condemned to Death. 1932.

GOODEN, ARTHUR HENRY.
Below the Deadline. 1920.

Ghost of the Rancho. © 1918.
Lawless Men. © 1924.
Scarlet Brand. (Serial)
Verdict of the Desert. © 1924.

GOODENOUGH, MARIE E.
Central Plains. 1920.
Great Plains. 1920.
Middle Atlantic States. 1921.
New England. 1921.
Pacific Mountains and Lowlands. 1921.
Rocky Mountains. 1921.

GOODERHAM AND WORTS, LTD.
Let's Talk It Over. 1936.

GOODHUE, WILLIS M.
Fixer. 1915.

GOODMAN, DANIEL CARSON.
Beyond All Is Love. 1915.
Love's Toll. 1916.
Orgy. 1915.
Silent Accuser. 1915.
Son. 1915.
Souls in Bondage. 1916.
Think Mothers. 1915.
Those Who Toil. 1916.
When Youth Is Ambitious. 1915.
*Zudora. (Serial)

GOODMAN (DANIEL CARSON) CORPORATION.
*Daring Years. 1923.
*Has the World Gone Mad! 1923.

GOODMAN, ECKERT.
In Hollywood with Potash and Perlmutter. 1924.
Just Outside the Door. 1920.
Love's Crucible. © 1916.

Man Who Played God. 1922, 1932.
Man Who Stood Still. © 1916.
Mother. © 1914.
Partners Again. 1926.
Two Natures Within Him. 1915.

GOODMAN, JACK.
Meet the Missus. 1937.

GOODMAN, JULES ECKERT. SEE Goodman, Eckert.

GOODMAN PRODUCTIONS, INC.
*What's Wrong with the Women? 1922.

GOODRICH.
Making Money in Your Own Business. 1936.

GOODRICH, ARTHUR FREDERICK.
Business and Pleasure. 1931.
So This Is London. 1930.

GOODRICH (B. F.) COMPANY, Akron, Ohio.
Amazing Life-Saver Tread. 1938.
Blowouts Take No Holiday. 1938.
Careful Drivers. 1938.
Danger Takes a Holiday. 1938.
Eye Witness. 1938.
Eyes Under the Fenders. 1936.
Farmer Rides on Rubber. 1937.
Front Page News. 1938.
Good News. 1938.
*Goodrich Silvertown News. © 1935.
*Highway Patrol. © 1935.
I'd Rather Be Your Wife Than Your Widow. 1938.
Keep Off the Accident List. 1938.
Life's Flat Moments. 1938.
*Love, Honor, and Obey the Law. © 1935.
New Kind of Tire. 1938.
Proof of the Pudding. 1938.

Quicker, Safer Stop. 1938.
Quit Your Skidding. 1938.
Reaching Out for More Sales. 1936.
Safest Thing on Wheels. 1938.
Safety Demonstration. 1938.
Safety First. 1938.
Safety Silvertown Stops. 1938.
Selling the Golden Ply. 1936.
Sensational New Tire. 1938.
Straight Line Stops. 1938.
Thrill of a Lifetime. 1938.
Tire That Saves Lives. 1938.
*Trucking Topics. © 1935.
Tubes, Tubes, Tubes. 1936.
When It Rains It Stops. 1938.
Year's Safety Sensation. 1938.

GOODRICH, FRANCES.
Thanks for the Memory. 1938.
Up Pops the Devil. 1931.

GOODRICH ASSOCIATED LINES.
Sell Safety—Diamond Tires. 1936.
Sell Safety—Hood Tires. 1936.
Sell Safety—Miller Tires. 1936.
Talk Tires—Diamond Version. 1936.
Talk Tires—Hood Version. 1936.
Talk Tires—Miller Version. 1936.

GOODRICK, JOHN B.
Pa and Ma Elope. © 1914.

GOODWIN, JOHN. SEE Gowing, Sidney Floyd.

GOODWIN, JOHN CUTHBERT.
Brooding Eyes. 1926.

GOODWIN, JULES ECKHARDT.
Man Who Came Back. 1930.

GOODWIN, MAUD WILDER.
Peter Stuyvesant. © 1924.

GOODYEAR, CHARLES.
Fools Who Made History. (Serial)

GOODYEAR TIRE AND RUBBER COMPANY.
*Conquering the Jungle. 1920.
*Island of Yesterday—Sumatra, Dutch West Indies. 1920.

GOOKINS, LAWRENCE GALE.
*Rhythm in the Air. © 1937.

GORDIN, JACOB.
Kreutzer Sonata. 1915.

GORDON, ALVIN J. SEE Contemporary Films.

GORDON, CHARLES WILLIAM.
Cameron of the Royal Mounted. 1921.
Heart of a Lion. 1917.
Sky Pilot. 1921.

GORDON, EDWARD.
Flirt and the Bandit. © 1913.

GORDON, HOMER KING.
Rip Roaring Riley. 1935.

GORDON, KILBOURN.
Kongo. 1932.

GORDON, LEON.
Garden of Weeds. 1924.
White Cargo. 1930.

GORDON, MAX.
Dodsworth. 1936.
Farmer Takes a Wife. 1935.

GORDON, NEIL E.
*Chemical and Physical Properties of Water. © 1932.
*Cosmic Ray. © 1932.

*Hydrogen and Oxygen. © 1932.
*Some Biochemical, Pharmacological, and Medical Stories as Told to Chemists. © 1932.

GORE-BROWNE, ROBERT.
Cynara. 1932.
Key. 1934.

GORMAN, HERBERT SHERMAN.
Suzy. 1936.

GORMAN, JACK.
Stampede. © 1913.
Stampede of Fate. © 1914.

GORMAN, JOHN.
Butterfly Girl. © 1921.
Prince of Broadway. 1925.

GORMAN FILM MANUFACTURING COMPANY, INC.
*Stampede. © 1913.
*Stampede of Fate. © 1914.

GORMLEY, HELEN V.
Legend of Black Rock. © 1914.

GORSSE, HENRY JOSEPH AUGUSTE DE.
Studio Girl. 1918.

GOTHAM.
Bare Knees. 1928.
Block Signal. 1926.
Chorus Kid. 1928.
Final Extra. 1927.
Golden Web. 1926.
Head of the Family. 1928.
Hearts and Spangles. 1926.
His Master's Voice. 1925.
King of the Pack. 1926.
Money to Burn. 1926.

Mountains of Manhattan. 1927.
One of the Bravest. 1925.
Overland Limited. 1925.
Part Time Wife. 1925.
Quarantined Rivals. 1927.
Racing Blood. 1926.
River Woman. 1928.
Shadow on the Wall. 1925.
Shattered Lives. 1925.
Sign of the Claw. 1926.
Silent Power. 1926.
Sinews of Steel. 1927.
Speed Limit. 1926.
Through the Breakers. 1928.
Turn Back the Hours. 1928.

GOTHAM FILM COMPANY.
Life of Big Tim Sullivan. © 1914.

GOTHAM PRODUCTIONS.
*Defying the Law. 1924.
*Silent Pal. 1925.

GOTHIC.
Forbidden Cargo. 1925.
Midnight Molly. 1925.
Parisian Nights. 1924.

GOTHIC PICTURES.
Silk Stocking Sal. 1924.

GOTTHART, BERNHARD.
Freiburg Passion Play. 1924.
Passion Play. © 1925.

GOTTLER, ARCHIE.
Archie Gottler—His Songs Are in Millions of Homes. 1928.

GOTTSCHALK, L. F.
Billy's Wager. 1914.

GOTTSMAN, SAMUEL.
Kol Nidre. © 1931.

GOTTWALD, FRITZ.
Boudoir Diplomat. 1930.

GOULD, CHESTER.
Dick Tracy. (Serial)
Dick Tracy Returns. (Serial)
Dick Tracy's G-men. (Serial)

GOULD, VENITA.
Venita Gould ... Offers ... Way Down Yonder in New Orleans.... 1927.

GOULDING, ALF.
Atta Boy. © 1926.

GOULDING, EDMOND.
Till We Meet Again. © 1922.

GOULDING, EDMUND.
Dancing Mothers. 1926.
Devil. © 1920.
Fury. 1922.
Happiness Ahead. 1928.
No Man of Her Own. 1933.
Trespasser. 1929.

GOVE, EDGAR A.
Harbor of Happiness. 1916.
Over Here. © 1917.

GOWING, SIDNEY FLOYD.
Avenger. 1933.
Without Mercy. 1925.

GRACE, DICK.
Lost Squadron. 1932.

GRAEME, BRUCE, pseud. SEE Jeffries, Graham Montague.